



Development and Evaluation of an Arduino-Based Automatic Timer for Uniformly Accelerated Linear Motion in Physics Learning

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ABSTRACT

Purpose of the study: This study aims to develop an Arduino Uno- and infrared sensor-based automatic timer for uniformly accelerated linear motion (UALM), evaluate its feasibility, assess student responses, and examine changes in conceptual understanding.

Methodology: This study employed a research and development (R&D) approach adapted from Sugiyono's model. The apparatus integrated an Arduino Uno R3, four infrared sensors, an LCD, and an adjustable inclined track, programmed using Arduino IDE. Data were collected from 12 tenth-grade students through interviews, questionnaires, technical tests, and pretest–posttest assessments. Analyses included Aiken's V, descriptive statistics, R^2 , paired-samples t-tests using SPSS 22, and normalized gain (N-gain).

Main Findings: The apparatus achieved an overall Aiken's V coefficient of 0.77, indicating validity according to the study's criteria. Student responses reached 91.8%, categorized as very good. Differences between measured and theoretically calculated travel times ranged from 0.03 to 0.10 seconds, while comparisons between sensor-based and stopwatch measurements yielded an R^2 of 0.9967. Pretest–posttest results showed a statistically significant difference ($p < 0.001$), with an N-gain of 0.47, indicating moderate improvement in conceptual understanding.

Novelty/Originality of this study: This study presents an integrated, classroom-oriented UALM teaching aid combining an adjustable inclined track, four infrared sensors, an Arduino Uno R3, and an LCD for automatic measurement and display of two time intervals. Its originality lies in the apparatus configuration, practical design modifications, and combined evaluation of expert validity, technical performance, student responses, and preliminary learning outcomes in secondary-school physics education.

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1. INTRODUCTION

Physics education requires students to connect theoretical principles with observable phenomena through meaningful experimentation, measurement, and evidence-based reasoning. Uniformly accelerated linear motion (UALM) is an important kinematics topic because it involves relationships among time, displacement, velocity, and acceleration [1], [2]. Understanding these relationships requires more than memorizing mathematical equations; students must also interpret experimental evidence and relate observations to physical principles [3]–[5]. Experimental learning provides opportunities for students to test predictions, analyze

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measurements, and develop conceptual understanding through direct engagement with physical phenomena [6]-[8]. Accordingly, well-designed experimental apparatuses can help bridge the gap between abstract kinematics concepts and students' observable learning experiences.

Despite the importance of experimental learning, opportunities to investigate UALM may be limited when physics instruction relies heavily on teacher explanations and provides insufficient practical learning media. This issue was identified at State Senior High School 1 Ketanggungan through a physics teacher interview conducted in July 2026, which indicated limited instructional media and a predominance of lecture-based teaching. Under these conditions, students may have fewer opportunities to observe motion directly and connect measured quantities with kinematics principles [9]-[11]. Furthermore, manual time measurement can introduce practical difficulties when students must simultaneously observe moving objects and record their travel times [12], [13]. These conditions indicate the need for an accessible experimental apparatus that facilitates time measurement while supporting students' conceptual understanding of UALM [14]-[16].

To address this problem, the present study develops an automatic-timer-based UALM teaching aid that integrates an Arduino Uno microcontroller, infrared sensors, an LCD, and an inclined track. The infrared sensors detect the moving object at designated measurement points, while the Arduino processes the timing information and displays the results on the LCD [17]-[19]. This configuration is intended to make motion measurements more systematic and provide students with quantitative data for investigating accelerated motion [20], [21]. Previous research suggests that carefully designed hands-on experiments can support conceptual learning and help address misconceptions in physics, highlighting the educational potential of practical investigation [22]. However, the value of the proposed apparatus must be assessed not only through its technical feasibility but also through student responses and changes in conceptual understanding.

Recent studies have explored how physical experiments, digital technologies, and virtual environments can support students' understanding of scientific concepts. Flegr et al. [23] examined the combination of real and virtual experiments, highlighting the potential learning benefits of integrating complementary experimental approaches. Research published in the *Journal of Science Education and Technology* has also compared physical and virtual inquiry-based experiments to investigate their relationships with students' attitudes and learning outcomes. Coleman and Hosein [24] investigated preparatory laboratory simulations and their potential to support conceptual knowledge and student engagement in engineering education. Furthermore, Wang et al. [25], synthesized evidence on combining real and virtual physics experiments, emphasizing the importance of examining how experimental configurations relate to learning achievement.

Although previous studies have examined physical experiments, virtual simulations, and digitally supported laboratory activities, these approaches do not directly establish the educational value of the specific automatic-timing apparatus developed in this study. Existing research on experimental learning also indicates the need to distinguish the availability of practical activities from evidence that students develop a deeper conceptual understanding [24]-[27]. In particular, an apparatus combining an inclined track, an Arduino Uno, infrared sensors, and automatic time display requires evaluation within the specific context of UALM instruction. Such evaluation should extend beyond product feasibility to include students' responses and changes in conceptual-understanding scores following its use. Therefore, the present study addresses this context-specific need by examining the apparatus's feasibility and its preliminary educational outcomes among students at Ketanggungan 1 Public High School.

The novelty of this research lies in the development and evaluation of an instructional apparatus for uniformly accelerated linear motion that integrates an Arduino Uno, infrared sensors, an automatic timer, and an inclined plane track. This configuration is designed to facilitate the observation of an object's motion while simultaneously displaying time measurements on an LCD screen [28], [29]. The integration of hardware and experimental activities enables students to compare observational data with theoretical predictions regarding uniformly accelerated linear motion [30]-[32]. The research also demonstrates originality by combining expert validation, device testing, student feedback, and the evaluation of conceptual understanding into a single development process. Thus, the contribution of this research does not claim that the use of Arduino or infrared sensors constitutes a new technology; rather, its contribution lies in the development of the device configuration and the evaluation of its application in learning, specifically within the context of uniformly accelerated linear motion.

Developing accessible experimental media for UALM is important because students need opportunities to connect observable motion with quantitative measurement and conceptual reasoning. This need is particularly relevant in schools where instructional media and opportunities for experimental physics learning are limited. Accordingly, this study aims to develop an automatic-timer-based UALM teaching aid using an Arduino Uno and infrared sensors and evaluate its feasibility as a physics learning medium. It also examines student responses and changes in conceptual-understanding scores by comparing pretest and posttest results after the apparatus is used. The findings are expected to provide preliminary evidence of the apparatus's educational potential and inform future investigations involving larger samples, comparison groups, and more extensive measurement-accuracy testing.

2. RESEARCH METHOD

2.1. Research Design

This study employed a research and development (R&D) approach to develop and evaluate an automatic-timer-based teaching aid for uniformly accelerated linear motion (UALM). The development procedure was adapted from Sugiyono's model and implemented through six stages: initial research and information gathering, planning, product design and development, expert validation, product revision, and field testing [33], [34]. A one-group pretest–posttest design was used to obtain preliminary evidence of changes in students' conceptual understanding following the use of the apparatus. Product evaluation covered expert-assessed validity, technical performance, student responses, and pretest–posttest results. The study was conducted at Ketanggungan 1 Public High School, Indonesia.

2.2. Development Procedures

The development process began with an initial investigation of instructional needs. A physics teacher interview conducted in July 2026 identified limited learning media and the predominance of lecture-based instruction in teaching UALM. These findings informed the planning stage, which involved reviewing relevant physics learning materials, curriculum requirements, and the components needed to construct the apparatus.

During product development, an inclined wooden track, a toy car, adjustable wooden blocks, an Arduino Uno microcontroller, infrared sensor modules, an LCD, and supporting electronic components were assembled. Arduino IDE was used to program the microcontroller to detect objects passing the sensors and display the measured time on the LCD. The adjustable blocks enabled variations in the track inclination during experimentation.

The prototype was subsequently assessed by expert validators to determine its suitability and identify aspects requiring revision. The apparatus was revised in accordance with the validation feedback before proceeding to technical testing and classroom implementation. During the field trial, students were introduced to the apparatus, completed a pretest, participated in a demonstration and experimental activity, responded to a questionnaire, and completed a posttest.

2.3. Participants and Sampling

The field trial was conducted with 12 tenth-grade students from classes X8–X10 at Ketanggungan 1 Public High School. Participants were selected using purposive sampling based on their initial physics competency scores, with the intention of including students with low, moderate, and high levels of prior achievement. Students who had studied or were studying relevant physics measurement and linear-motion concepts were considered suitable for the trial. This small-scale implementation was intended to examine the usability of the developed apparatus and obtain preliminary evidence of changes in conceptual understanding. The limited sample size and absence of a control group were considered when interpreting the findings.

2.4. Research Instruments and Data Collection

Data were collected through teacher interviews, expert-validation questionnaires, a student-response questionnaire, conceptual-understanding tests, and technical testing of the apparatus. Table 1 summarizes the instruments, their purposes, and the data obtained.

Table 1. Research instruments and data collection

Instrument or method	Purpose	Data obtained
Teacher interview	Identify instructional needs and limitations in existing UALM learning media	Qualitative information about teaching practices and learning needs
Expert-validation questionnaire	Assess the suitability of the developed apparatus	Expert ratings for validity analysis using Aiken's V
Student-response questionnaire	Examine students' perceptions of the apparatus and its use	Questionnaire scores and ideality percentage
Pretest and posttest	Assess students' conceptual understanding before and after using the apparatus	Individual test scores and changes in mean scores
Technical apparatus testing	Examine the operation of the sensors and automatic timer	Measured travel times and comparisons with theoretical values

The teacher interview was conducted during the initial research stage and informed the design requirements. Expert validators assessed the apparatus using the validation instrument provided in the thesis. Students completed the response questionnaire after using the apparatus; the instrument contained 15 items

addressing design, operation, and instructional functions. Conceptual understanding was assessed through pretest and posttest instruments administered before and after the learning activity, respectively.

2.5. Apparatus Design and Technical Testing

The teaching aid consisted of a wooden track, a toy car, adjustable wooden blocks, an Arduino Uno microcontroller, infrared sensor modules, an LCD, and supporting electronic components. The wooden track was 120 cm long and 13 cm wide, while the adjustable blocks allowed the track inclination to be varied. Arduino IDE was used to program the microcontroller to detect the passage of an object and display the measured time on the LCD. The apparatus was tested by measuring travel times and comparing the experimental results with theoretical calculations under the specified conditions. The original study also reported a friction-related coefficient of 0.06, indicating that friction needed to be considered when interpreting the motion measurements.

2.6. Data Analysis

The collected data were analyzed according to the purpose of each instrument. Expert-validation data were analyzed using Aiken's V, while student-response data were converted into an ideality percentage and interpreted using the evaluation criteria adopted in the original study. Technical performance was examined by comparing measured travel times with theoretical values to identify discrepancies between experimental and calculated results.

For the learning-outcome analysis, pretest and posttest scores were summarized using descriptive statistics. The original study used the Kolmogorov–Smirnov test to assess normality and Levene's test to examine variance homogeneity. A paired-samples t-test was then conducted in SPSS version 22 at a significance level of 0.05 to determine whether the mean pretest and posttest scores differed significantly [35], [36]. Because a paired-samples t-test concerns within-participant differences, the final analysis should assess the distribution of those differences rather than treating Levene's test as a required assumption.

Learning improvement was additionally assessed using normalized gain (N-gain), calculated as:

$$g = \frac{S_{\text{post}} - S_{\text{pre}}}{S_{\text{max}} - S_{\text{pre}}} \quad \dots(1)$$

where S_{post} is the posttest score, S_{pre} is the pretest score, and S_{max} is the maximum possible score. The study interpreted gain percentages of 67–100% as high, 33–66% as moderate, and below 33% as low. The N-gain result was interpreted alongside the paired-samples t-test to distinguish the magnitude of score improvement from its statistical significance.

2.7. Ethical Considerations

The available thesis information does not establish whether formal ethical approval, parental consent, or student assent was obtained. These details should therefore be confirmed from the original research records and reported in the manuscript according to the journal's requirements. Any statement about ethical approval or informed consent should reflect the procedures actually followed during data collection.

3. RESULTS AND DISCUSSION

3.1. Development of the Automatic-Timer-Based UALM Teaching Aid

The developed teaching aid was designed to support the learning of uniformly accelerated linear motion (UALM) through direct observation and measurement of motion. The apparatus consists of a straight inclined track, a toy car, four infrared sensors, an Arduino Uno R3 microcontroller, an LCD, connecting wires, sensor housings, and adjustable supports. The integration of these components enables students to observe motion and obtain time measurements automatically during experimental activities.

The final prototype is presented in Figure 1. The apparatus uses an inclined track as the path of motion for the toy car. Four infrared sensors are positioned along the track to detect the car as it passes designated points. The sensors are connected to the Arduino Uno R3, which processes the signals and controls the display of the measured time intervals on the LCD. This configuration allows students to obtain measurement data without relying solely on manual stopwatch operation.



Figure 1. Final prototype of the automatic-timer-based UALM teaching aid

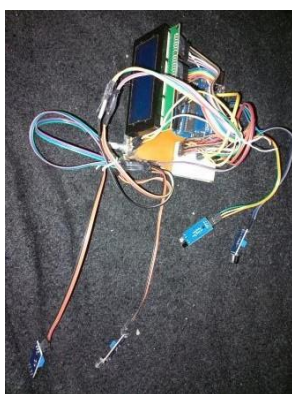
The measurement system was configured to record two time intervals. The first infrared sensor initiates the first timing interval, and the second sensor terminates it. The third sensor initiates the second interval, while the fourth sensor terminates it. The Arduino Uno R3 processes the signals received from the sensors and displays the corresponding measurement results on the LCD. The hardware configuration of the system is shown in Figure 2.



Figure 2. Hardware configuration of the automatic-timer-based UALM teaching aid

The prototype underwent several revisions during the development process. First, a user guide was added to support the operation of the apparatus. Second, the number of infrared sensors was increased from two to four to enable the measurement of two time intervals. Third, the motorized toy car was replaced with a manually operated toy car to reduce the influence of motor-generated motion on the experiment. Fourth, the supporting structure was modified to allow adjustment of the track inclination. Finally, protective housings were added to the infrared sensors to improve their physical protection during use.

The principal revisions are presented in Figure 3. These modifications were intended to improve the functionality, usability, and suitability of the apparatus for classroom experiments on uniformly accelerated linear motion.



(a)



(b)



(c)

Figure 3. Revisions to the teaching aid: (a) addition of infrared sensors, (b) replacement of the motorized toy car with a manually operated toy car, and (c) installation of protective housings for the sensors.

Overall, the developed teaching aid integrates motion experimentation, automatic time measurement, and digital data display in a single apparatus. Its configuration provides students with an opportunity to collect experimental data and relate the measured time intervals to the characteristics of uniformly accelerated linear motion. The product was subsequently evaluated through validation and testing procedures, with the results reported in the following sections.

3.2. Expert Validation of the Teaching Aid

Expert validation was conducted to evaluate the suitability of the developed teaching aid as a learning medium for UALM. Two validators assessed the product using criteria related to learning, the physical design of the apparatus, product quality, and functionality. The assessment results were analyzed using Aiken's V coefficient. The validation results are presented in Table 2.

Table 2. Expert validation results for the developed teaching aid

Assessment aspect	Validator 1 mean score	Validator 2 mean score	Aiken's V	Category
Learning aspect	3.50	3.50	0.76	Valid
Apparatus design	3.40	3.40	0.79	Valid
Apparatus quality	3.00	3.66	0.77	Valid
Apparatus functionality	3.00	3.66	0.77	Valid
Overall result	3.23	3.56	0.77	Valid

As shown in Table 2, the overall Aiken's V coefficient was 0.77, indicating that the teaching aid met the validity criteria used in the study. The apparatus-design aspect obtained the highest coefficient (0.79), while the learning aspect obtained a coefficient of 0.76. The product-quality and functionality aspects each obtained a coefficient of 0.77.

These findings indicate that the apparatus was considered suitable for further testing as a physics learning medium. The integration of an inclined track, infrared sensors, a microcontroller, and an LCD provides a practical means of conducting motion experiments and displaying measurement results. Nevertheless, expert validation establishes the assessed suitability of the product; it does not, by itself, establish measurement accuracy or improved student learning outcomes. These aspects therefore require separate evaluation.

3.3. Technical Performance of the Teaching Aid

The technical performance of the apparatus was evaluated by comparing measured travel times with theoretical calculations for different moving objects. The comparison was intended to examine whether the apparatus produced measurements that were reasonably consistent with the calculated values under the experimental conditions. The results are presented in Table 3.

Table 3. Comparison of measured and theoretically calculated travel times

Test object	Apparatus measurement (s)	Theoretical calculation (s)	Absolute difference (s)
Small cylinder	2.18	2.13	0.05
Toy car	2.25	2.22	0.03
Large cylinder	2.22	2.32	0.10

As shown in Table 3, the smallest difference was recorded for the toy car, at 0.03 s, followed by the small cylinder, at 0.05 s. The largest difference was observed for the large cylinder, at 0.10 s. The discrepancies between measured and calculated values may be associated with friction acting on the track and the moving objects. The original study reported a friction coefficient of 0.06.

The apparatus was also evaluated by comparing the time measurements obtained from the infrared sensor system with measurements from a stopwatch. The relationship between the two datasets yielded a coefficient of determination (R^2) of 0.9967. This indicates a strong linear relationship between the compared measurements under the tested conditions.

However, the coefficient of determination should not be interpreted directly as an accuracy percentage. A high (R^2) indicates that the measurements follow a strong linear relationship, whereas accuracy requires an assessment of the differences between measured values and an accepted reference standard. Accordingly, the reported results support the potential of the apparatus for time-measurement activities, while further reporting of calibration data, measurement errors, and repeated trials would provide a more comprehensive evaluation of its technical performance.

3.4. Student Responses to the Teaching Aid

Student responses were collected to assess the perceived quality and usability of the developed teaching aid. The small-scale response assessment involved 12 students selected to represent different levels of prior physics achievement. After receiving instructions, the students used the apparatus and completed a response questionnaire.

The overall results are summarized in Table 4.

Table 4. Summary of student responses to the teaching aid

Assessment indicator	Result
Number of respondents	12
Total response score	661
Mean score	55.08
Ideality percentage	91.8%
Overall category	Very Good

The results show an overall ideality percentage of 91.8%, classified as “Very Good” in the original study. This finding indicates that the students responded favorably to the developed teaching aid in the small-scale evaluation.

The positive response may be related to the opportunity to observe motion directly and obtain travel-time measurements through the LCD display. The use of infrared sensors also provides a structured procedure for identifying when an object passes designated measurement points. These features may make experimental activities more accessible and help students connect observations with quantitative data.

Nevertheless, the response questionnaire measures students’ perceptions of the apparatus rather than their actual conceptual understanding. The high response percentage should therefore be interpreted as evidence of favorable perceived quality and usability, not as a direct measure of learning effectiveness. The instructional value of the apparatus must also be considered alongside the results of the pretest–posttest assessment.

3.5. Effectiveness of the Teaching Aid in Learning UALM

The instructional effectiveness of the developed teaching aid was examined by comparing students’ learning outcomes before and after the learning activities. The original study reported a statistically significant difference between pretest and posttest scores, with a significance value of 0.000 in the statistical output. This value should be reported as ($p < 0.001$), rather than as an exact probability of zero.

The normalized gain (N-gain) was 0.47, corresponding to an improvement percentage of approximately 47%. According to the classification used in the original study, this value fell within the moderate N-gain category and was interpreted as indicating that the apparatus was sufficiently effective in the tested instructional setting.

The effectiveness results are summarized in Table 5.

Table 5. Summary of instructional effectiveness results

Indicator	Reported result	Interpretation
Pretest–posttest hypothesis test	($p < 0.001$)	Statistically significant difference
N-gain	0.47	Moderate improvement
N-gain percentage	Approximately 47%	Sufficiently effective according to the original study’s criteria

The statistically significant difference indicates that students’ test performance changed between the pretest and posttest. The N-gain result further suggests that the improvement was moderate rather than maximal. These findings provide preliminary evidence that learning activities using the automatic-timer-based UALM teaching aid were associated with improved student performance in the study setting.

The apparatus may support learning by connecting abstract motion concepts with observable experimental data. Students can observe an object moving along an inclined track, record the time intervals detected by the infrared sensors, and examine the displayed results. Such activities provide opportunities to relate experimental observations to the quantitative description of motion.

However, the results should be interpreted in light of the study design and sample. The instructional evaluation was conducted on a limited scale, and the reported pretest–posttest comparison does not, by itself, establish that the apparatus was the sole cause of the observed improvement. A larger study involving a comparison group would provide stronger evidence regarding its effectiveness relative to other instructional approaches [37], [38].

The findings indicate that the automatic-timer-based uniformly accelerated linear motion (UALM) teaching aid demonstrates promising potential as a physics learning medium, although its technical quality and instructional effectiveness should be interpreted separately. The expert validation coefficient (Aiken’s $V = 0.77$) supports the assessed validity of the apparatus, while the student response score of 91.8% indicates favorable perceptions of its usability and learning potential. The technical measurements also showed relatively small differences between the apparatus readings and theoretical calculations, ranging from 0.03 to 0.10 s. In addition, the reported coefficient of determination ($R^2 = 0.9967$) indicates a strong linear relationship between the sensor-based measurements and the comparison measurements. However, this coefficient does not independently establish measurement accuracy, and the moderate N-gain of 0.47 provides evidence of improvement without

demonstrating that the apparatus alone caused the learning gains. Taken together, the findings suggest that the apparatus is a promising instructional innovation, but further calibration, repeated measurements, and controlled learning evaluations are required to establish its technical reliability and educational effectiveness more conclusively.

The present findings are consistent with research emphasizing that experimental equipment plays an important role in shaping students' opportunities to observe and interpret physical phenomena. Bernhard [39], in a study of students investigating motion on an inclined plane using different measurement technologies, demonstrated that the equipment used influences which features of a physical phenomenon students can discern and learn. This perspective supports the design of the present apparatus, in which infrared sensors and an LCD make selected motion measurements more accessible to students. Nevertheless, the favorable response and moderate learning gains in the present study should not be interpreted as evidence that automated measurement automatically produces deeper conceptual understanding. Winkelmann et al. [40], in a large-scale study involving 1,507 students, found no significant differences in content knowledge acquisition across three practices of classroom experimentation, highlighting the importance of instructional processes rather than the mere presence of experimental activities. Similarly, Tenzin et al. [34] reported that a combined simulation and hands-on strategy was more effective for conceptual understanding of electric circuits than either strategy used separately. Their findings suggest that the teaching aid developed in the present study may be more effective when integrated with prediction, guided investigation, data interpretation, and reflective discussion rather than used only to demonstrate motion or record time. Further support comes from Coştu and Bayram [41], who found that laboratory activities organized around predicting, explaining, observing, and discussing significantly improved prospective teachers' conceptual understanding. Coleman and Hosein [24] also reported that preparatory laboratory simulations helped students visualize concepts, explore scenarios, and develop confidence in their understanding, although overall laboratory assessment scores did not differ significantly between cohorts. Collectively, these studies support the potential value of technology-enhanced experimentation while emphasizing that equipment, instructional guidance, and opportunities to interpret evidence need to work together.

The novelty of this study lies in the development and preliminary evaluation of an integrated, automatic-timer-based teaching aid specifically designed for UALM. Unlike an apparatus that relies solely on manual stopwatch operation, the developed product combines an inclined track, four infrared sensors, an Arduino Uno R3 microcontroller, and an LCD to capture and display two motion-time intervals within a single experimental setup. The development process also incorporated practical design modifications, including replacing the motorized car with a manually operated car, making the track inclination adjustable, and adding protective sensor housings. These features represent a context-specific design contribution that connects physical experimentation with automated time measurement in a classroom-oriented device. The study further combines expert validation, comparison with theoretical travel times, comparison with stopwatch measurements, student responses, and a preliminary pretest–posttest evaluation. The contribution should therefore be understood as an integrated design and initial evaluation of a specific teaching aid, rather than as proof that the device is superior to all existing motion-measurement systems. Its distinctive value is the combination of accessible hardware, a defined measurement procedure, and preliminary evidence of feasibility for secondary-school physics instruction [42], [43].

The findings have practical implications for physics teachers, teaching-aid developers, and schools seeking to provide more concrete experimental experiences in mechanics. For teachers, the apparatus can be used to organize learning activities in which students predict the motion of an object, collect time data, compare measurements with theoretical expectations, and discuss possible discrepancies. Such activities can shift laboratory work beyond following procedures toward interpreting evidence and explaining physical relationships. For developers, the differences between measured and theoretical travel times emphasize the need to improve sensor positioning, standardize release procedures, calibrate the timing system, and account for friction and other experimental uncertainties. For schools, the use of commonly available electronic components may offer a practical option for supporting experimental learning where access to specialized equipment is limited, although the actual cost, durability, and maintenance requirements should be assessed before broader implementation. At the research level, the moderate N-gain indicates that future studies should examine not only whether scores improve, but also which instructional activities help students connect measured time intervals with displacement, velocity, and acceleration. A more informative evaluation would combine conceptual tests with students' experimental reports, observations of inquiry processes, and analyses of measurement errors.

The findings should be generalized cautiously because the instructional response assessment and learning evaluation involved only 12 students in a small-scale trial. The results provide preliminary evidence of feasibility and potential educational value, but they cannot establish that the same outcomes would occur across different schools, grade levels, teachers, or laboratory conditions. The technical evaluation also has limitations: the reported comparison involved a limited set of objects and time measurements, and the coefficient of determination does not replace direct estimates of measurement error, uncertainty, or agreement with a calibrated

reference instrument. In addition, the pretest–posttest results were obtained without a reported control group, so factors such as prior knowledge, teacher guidance, repeated testing, and other learning activities may have contributed to the observed improvement. The findings are therefore most appropriately interpreted as evidence supporting further development and testing, rather than definitive causal evidence of instructional effectiveness. Future research should involve larger and more diverse student samples, repeated trials across different track inclinations and moving objects, explicit calibration against a reliable reference, and a comparison group using conventional experimental procedures. Such studies would help establish the reproducibility, measurement performance, and wider applicability of the apparatus in physics education.

4. CONCLUSION

This study concludes that the automatic-timer-based uniformly accelerated linear motion (UALM) teaching aid was successfully developed by integrating four infrared sensors, an Arduino Uno R3, an inclined track, and an LCD to measure the travel time of objects automatically. Expert validation yielded an overall Aiken's V value of 0.77, while student responses reached 91.8%, categorized as very good. The technical testing revealed a very strong relationship between the sensor-based measurements and stopwatch measurements ($R^2 = 0.9967$), while the instructional implementation achieved a normalized gain (N-gain) of 0.47, indicating a moderate improvement. These findings suggest that the developed apparatus is a promising and engaging instructional tool for supporting students' understanding of UALM concepts, although its instructional effectiveness requires further investigation. Future research should conduct more extensive technical testing with additional trials and varied experimental conditions to assess measurement consistency and identify potential sources of error. Further studies should also involve larger student samples and control groups to provide stronger evidence of the apparatus's effectiveness in improving students' conceptual understanding of UALM.

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REFERENCES

- [1] L. González-Rodríguez and A. Plasencia-Salgueiro, "Uncertainty-Aware autonomous mobile robot navigation with deep reinforcement learning," in Koubaa, A., Azar, A.T. (eds) *Deep Learning for Unmanned Systems. Studies in Computational Intelligence*, A. Koubaa and A. T. Azar, Eds., Cham: Springer International Publishing, 2021, pp. 225–257. doi: 10.1007/978-3-030-77939-9_7.
- [2] Mark E Pryer, John Cronin, Jonathon Neville, and Aaron Uthoff, "Kinematics and kinetics of pick-up acceleration," *Int. J. Sports Sci. Coach.*, vol. 20, no. 6, pp. 2796–2804, Dec. 2025, doi: 10.1177/17479541251350474.
- [3] V. Borish and H. J. Lewandowski, "Seeing quantum effects in experiments," *Phys. Rev. Phys. Educ. Res.*, vol. 19, no. 2, p. 20144, Oct. 2023, doi: 10.1103/PhysRevPhysEducRes.19.020144.
- [4] Z. Patterson and L. Ding, "Epistemic framing analysis of secondary students during instruction on quantum physics," *Phys. Rev. Phys. Educ. Res.*, vol. 21, no. 1, p. 10116, Mar. 2025, doi: 10.1103/PhysRevPhysEducRes.21.010116.
- [5] P.-H. Liu, "A structuralist view for interpreting the role of mathematics in physics," *ZDM – Math. Educ.*, vol. 54, no. 7, pp. 1657–1670, 2022, doi: 10.1007/s11858-022-01438-3.
- [6] S. Puntambekar, D. Gnesdilow, C. Dornfeld Tissenbaum, N. H. Narayanan, and N. S. Rebello, "Supporting middle school students' science talk: A comparison of physical and virtual labs," *J. Res. Sci. Teach.*, vol. 58, no. 3, pp. 392–419, Mar. 2021, doi: <https://doi.org/10.1002/tea.21664>.
- [7] H. Van Le, "Silence in the classroom: Unraveling the cultural dynamics affecting participation and critical thinking in Malaysian and Vietnamese engineering education," *Cogent Educ.*, vol. 11, no. 1, p. 2404780, Dec. 2024, doi: 10.1080/2331186X.2024.2404780.
- [8] H. J. Banda and J. Nzabahimana, "Effect of integrating physics education technology simulations on students' conceptual understanding in physics: A review of literature," *Phys. Rev. Phys. Educ. Res.*, vol. 17, no. 2, p. 23108, Dec. 2021, doi: 10.1103/PhysRevPhysEducRes.17.023108.
- [9] M. Hitier and A. S. González-Martín, "Derivatives and the Study of Motion at the Intersection of Calculus and Mechanics: a Praxeological Analysis of Practices at the College Level," *Int. J. Res. Undergrad. Math. Educ.*, vol. 8, no. 2, pp. 293–317, 2022, doi: 10.1007/s40753-022-00182-z.
- [10] A. Cashman and T. O'Mahony, "Student understanding of kinematics: a qualitative assessment," *Eur. J. Eng. Educ.*, vol. 47, no. 6, pp. 886–909, Nov. 2022, doi: 10.1080/03043797.2022.2073200.
- [11] J. Tito Cruz, V. R. Coluci, and R. Moraes, "ORUN-VR2: A VR serious game on the projectile kinematics: design, evaluation, and learning outcomes," *Virtual Real.*, vol. 27, no. 3, pp. 2583–2604, 2023, doi: 10.1007/s10055-023-00824-w.
- [12] P. Alstein, K. Krijtenburg-Lewerissa, and W. R. van Joolingen, "Teaching and learning special relativity theory in

- secondary and lower undergraduate education: A literature review,” *Phys. Rev. Phys. Educ. Res.*, vol. 17, no. 2, p. 23101, Jul. 2021, doi: 10.1103/PhysRevPhysEducRes.17.023101.
- [13] F. Outay, H. A. Mengash, and M. Adnan, “Applications of unmanned aerial vehicle (UAV) in road safety, traffic and highway infrastructure management: Recent advances and challenges,” *Transp. Res. Part A Policy Pract.*, vol. 141, pp. 116–129, 2020, doi: 10.1016/j.tra.2020.09.018.
- [14] A. Salatino, A. Prével, E. Caspar, and S. Lo Bue, “Influence of AI behavior on human moral decisions, agency, and responsibility,” *Sci. Rep.*, vol. 15, no. 1, p. 12329, 2025, doi: 10.1038/s41598-025-95587-6.
- [15] Maria Teresa Restivo, Diana Urbano, and Maria Fátima Chouzal, “Instrumentation for measurement: A case study on conceptual versus problem-solving knowledge,” *Int. J. Mech. Eng. Educ.*, vol. 53, no. 2, pp. 411–431, Apr. 2025, doi: 10.1177/03064190241230057.
- [16] K. Achuthan, D. Raghavan, B. Shankar, S. P. Francis, and V. K. Kolil, “Impact of remote experimentation, interactivity and platform effectiveness on laboratory learning outcomes,” *Int. J. Educ. Technol. High. Educ.*, vol. 18, no. 1, p. 38, 2021, doi: 10.1186/s41239-021-00272-z.
- [17] K. SuriyaKrishna, G. Mahendra, D. Sankar, and K. S. Yamuna, “Wireless data transferring of soldier health monitoring and position tracking system using arduino,” in *Inventive Systems and Control. Lecture Notes in Networks and Systems*, V. Suma, Z. Baig, S. Kolandapalayam Shanmugam, and P. Lorenz, Eds., Singapore: Springer Nature Singapore, 2022, pp. 761–774.
- [18] S. M. N. Howlader, M. M. Hossain, S. Khanom, S. Sarker, and B. Barua, “An Intelligent Car Locating System Based on Arduino for a Massive Parking Place,” in *Multi-Strategy Learning Environment*, V. Vimal, I. Perikos, A. Mukherjee, and V. Piuri, Eds., Singapore: Springer Nature Singapore, 2024, pp. 19–33.
- [19] A. Mukhopadhyay, A. Rao, P. Joshi, and V. Harish, “Edge based blind spot avoidance and speed monitoring for emergency vehicles,” *Procedia Comput. Sci.*, vol. 235, pp. 284–302, 2024, doi: <https://doi.org/10.1016/j.procs.2024.04.030>.
- [20] R. Girwidz, H. Theyßen, and R. Widenhorn, “Experiments in physics teaching,” in *Physics Education*, H. E. Fischer and R. Girwidz, Eds., Cham: Springer International Publishing, 2021, pp. 269–296. doi: 10.1007/978-3-030-87391-2_10.
- [21] S. Becker, P. Klein, A. Gößling, and J. Kuhn, “Investigating dynamic visualizations of multiple representations using mobile video analysis in physics lessons: Effects on emotion, cognitive load and conceptual understanding,” *Zeitschrift für Didakt. der Naturwissenschaften*, vol. 26, no. 1, pp. 123–142, 2020, doi: 10.1007/s40573-020-00116-9.
- [22] G. Liu and N. Fang, “The effects of enhanced hands-on experimentation on correcting student misconceptions about work and energy in engineering mechanics,” *Res. Sci. Technol. Educ.*, vol. 41, no. 2, pp. 462–481, 2023, doi: 10.1080/02635143.2021.1909555.
- [23] S. Flegr, J. Kuhn, and K. Scheiter, “When the whole is greater than the sum of its parts: Combining real and virtual experiments in science education,” *Comput. Educ.*, vol. 197, p. 104745, 2023, doi: 10.1016/j.compedu.2023.104745.
- [24] P. Coleman and A. Hosein, “Using voluntary laboratory simulations as preparatory tasks to improve conceptual knowledge and engagement,” *Eur. J. Eng. Educ.*, vol. 48, no. 5, pp. 899–912, Sep. 2023, doi: 10.1080/03043797.2022.2160969.
- [25] X.-M. Wang, X.-H. Yu, D. Yu, G.-J. Hwang, and M. Lan, “Does combining real and virtual experiments improve learning achievement in physics? Evidence from a meta-analysis (2001–2021),” *Educ. Res. Rev.*, vol. 46, p. 100661, 2025, doi: 10.1016/j.edurev.2024.100661.
- [26] J. Kranz, A. Baur, and A. Möller, “Learners’ challenges in understanding and performing experiments: A systematic review of the literature,” *Stud. Sci. Educ.*, vol. 59, no. 2, pp. 321–367, Jul. 2023, doi: 10.1080/03057267.2022.2138151.
- [27] A. Van den Beemt, S. Groothuijsen, L. Ozkan, and W. Hendrix, “Remote labs in higher engineering education: Engaging students with active learning pedagogy,” *J. Comput. High. Educ.*, vol. 35, no. 2, pp. 320–340, 2023, doi: 10.1007/s12528-022-09331-4.
- [28] M. Tong, S. Chen, Y. Niu, and C. Xue, “Effects of speed, motion type, and stimulus size on dynamic visual search: A study of radar human-machine interface,” *Displays*, vol. 77, p. 102374, 2023, doi: 10.1016/j.displa.2023.102374.
- [29] S. Han, “Improvement of an LCD-based calibration site for reliable focus-dependent camera calibration,” *KSCE J. Civ. Eng.*, vol. 26, no. 3, pp. 1365–1375, 2022, doi: 10.1007/s12205-021-5464-x.
- [30] K. Wang, “Dynamic prediction of adolescent sports injury probability based on the improved ARIMA model in the background of digital physical education teaching,” *Sci. Rep.*, vol. 16, no. 1, p. 1903, 2025, doi: 10.1038/s41598-025-31591-0.
- [31] K. Hippalgaonkar, Q. Li, X. Wang, J. W. Fisher, J. Kirkpatrick, and T. Buonassisi, “Knowledge-integrated machine learning for materials: Lessons from gameplaying and robotics,” *Nat. Rev. Mater.*, vol. 8, no. 4, pp. 241–260, 2023, doi: 10.1038/s41578-022-00513-1.
- [32] T. Pierratos, “Encounter with a rectilinear uniformly accelerated motion in a flipped classroom: Enhancing students’ data processing skills,” *Phys. Educ.*, vol. 56, no. 5, p. 55017, 2021, doi: 10.1088/1361-6552/ac080b.
- [33] R. Hartono and T. Pahlevi, “Development of assessment instruments based on hots at Surabaya vocational high school,” *JISAE J. Indones. Student Assess. Eval.*, vol. 6, no. 2 SE-Articles, pp. 210–218, Aug. 2020, doi: 10.21009/jisae.v6i2.15853.
- [34] P. C. Zulfiani and S. Sugiyono, “Developing an interactive learning multimedia basic competence for using facial care tools with technology in students of vocational education,” *J. Phys. Conf. Ser.*, vol. 1700, no. 1, p. 12089, 2020, doi: 10.1088/1742-6596/1700/1/012089.
- [35] K. Okoye and S. Hosseini, “T-test Statistics in R: Independent Samples, Paired Sample, and One Sample T-tests,” in *R Programming: Statistical Data Analysis in Research*, K. Okoye and S. Hosseini, Eds., Singapore: Springer Nature Singapore, 2024, pp. 159–186. doi: 10.1007/978-981-97-3385-9_8.
- [36] A. Hashemifardnia, S. Shafiee, F. Rahimi Esfahani, and M. Sepehri, “Effects of flipped instruction on iranien

- intermediate EFL learners' speaking complexity, accuracy, and fluency," *Cogent Educ.*, vol. 8, no. 1, p. 1987375, Jan. 2021, doi: 10.1080/2331186X.2021.1987375.
- [37] N. Barz, M. Benick, L. Dörrenbächer-Ulrich, and F. Perels, "The effect of digital game-based learning interventions on cognitive, metacognitive, and affective-motivational learning outcomes in school: A meta-analysis," *Rev. Educ. Res.*, vol. 94, no. 2, pp. 193–227, Apr. 2024, doi: 10.3102/00346543231167795.
- [38] B. Wu, X. Yu, and X. Gu, "Effectiveness of immersive virtual reality using head-mounted displays on learning performance: A meta-analysis," *Br. J. Educ. Technol.*, vol. 51, no. 6, pp. 1991–2005, Nov. 2020, doi: <https://doi.org/10.1111/bjet.13023>.
- [39] J. Bernhard, "What matters for students' learning in the laboratory? Do not neglect the role of experimental equipment!," *Instr. Sci.*, vol. 46, no. 6, pp. 819–846, 2018, doi: 10.1007/s11251-018-9469-x.
- [40] J. Winkelmann, S. F. C. Wenzel, M. Ullrich, H. Horz, and R. Erb, "Three practices of experimenting in the physics classroom – impact on students' content knowledge acquisition," *Int. J. Sci. Educ.*, vol. 48, no. 9, pp. 1311–1333, Jun. 2026, doi: 10.1080/09500693.2025.2453954.
- [41] F. Coştu and H. Bayram, "From cookbook lab to PEODE-based lab: Redesigning lab activities to foster conceptual understanding," *Res. Sci. Technol. Educ.*, vol. 43, no. 3, pp. 818–839, Jul. 2025, doi: 10.1080/02635143.2024.2342884.
- [42] F. E. Babalola, S. J. Fakoyede, F. B. Ojobola, M. A. Ayodeji, S. K. Ekundayo, and D. O. Alabi, "Evaluating the effectiveness of multimedia integration in enhancing physics instruction in secondary schools," *Discov. Educ.*, vol. 5, no. 1, p. 46, 2025, doi: 10.1007/s44217-025-00871-2.
- [43] J. M. May, "Historical analysis of innovation and research in physics instructional laboratories: Recurring themes and future directions," *Phys. Rev. Phys. Educ. Res.*, vol. 19, no. 2, p. 20168, Dec. 2023, doi: 10.1103/PhysRevPhysEducRes.19.020168.